

First record of the invasive true bug (Heteroptera) *Halyomorpha halys* (Stål, 1855) from Hamburg with other records from Northern Germany and possible implications for its range expansion

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Abstract

The invasive pentatomid true bug *Halyomorpha halys* is reported for the first time from the German state of Hamburg, along with records from several other locations in Northern Germany. Specimens collected by scientists were evaluated along with records from citizen science platforms. DNA barcode sequences of several *H. halys* specimens from Hamburg were evaluated along with 42 sequences of the species from across the world in a haplotype network analysis demonstrating that all specimens studied from Hamburg had the haplotype H3. The present state of distribution of *H. halys* in Germany, patterns of range extension, invasiveness, and possible economic impacts are discussed.

Key Words

biological invasions, neobiota, insect pests, accidental introduction, agricultural pest

Introduction

Hamburg, as one of the main harbor cities of Germany, has long been known as a major hub of non-native and invasive species. Already in 1900, Kraepelin reported almost 500 non-native species in the Hamburg harbor, many of which were insects (Kraepelin 1900). Similarly, Weidner later reported many non-native species for the city (e.g. Weidner 1974, 1981). More recently, records of neobiotic species from Hamburg, with apparently disjunct distributions in Germany were discovered, e.g., of the Asian Hornet *Vespa velutina* Lepeletier, 1836 (Husemann et al. 2020), or the heteropteran *Oxycarenus lavaterae* (Fabricius, 1787) (Troch and Husemann 2020). Further, several species have recently naturally expanded their distributions to northern Germany, e.g. *Pieris mannii* (Mayer, 1851) (Kolligs et al. in press). Most of these

species that arrive in Hamburg cannot establish or do not cause any damage. However, some species may represent a threat to the native ecosystems or to agriculture. One such species that has been causing economic damage globally (Leskey and Nielsen 2018) is the pentatomid true bug *Halyomorpha halys* (Stål, 1855).

Halyomorpha halys was originally distributed in mainland China, Hainan, Taiwan, Japan, Korea and Northern Vietnam (Josifov and Kerzhner 1978). Since the 1990s, it has been accidentally introduced to different countries throughout the world. In this context, Claerefort et al. (2018) and Cianferoni et al. (2018) provided the latest overviews on the worldwide distribution of the species. According to their summaries, *H. halys* is recorded for most US states, Canada, most countries of Europe (including Abkhazia and Georgia), Turkey, Kazakhstan, Chile, Puerto Rico and Egypt. Since those

most recent review works, *H. halys* was also recorded from the Netherlands (Aukema et al. 2019), Moldova (Derjanschi and Chimișliu 2019), Malta (Tassini and Mifsud 2019), Bosnia and Herzegovina (Zovko et al. 2019), Portugal (Grosso-Silva et al. 2020) and Great Britain (Powel et al. 2021). In several other countries, such as Australia (Claerebout et al. 2018, Horwood et al. 2019), New Zealand (Claerebout et al. 2018), Iceland (Cianferoni et al. 2018, Claerebout et al. 2018) and Guam (Moore 2014), the species was intercepted by biocontrol agencies, but is probably not established. For now, among European countries, only Ireland, Denmark, Finland, Estonia, Latvia, Lithuania and Belarus did not provide any records of the species.

In Germany, the first *H. halys* specimens were found in October 2011 at the port of Bremen in Northern Germany, arriving from the USA with a package of machine parts (Freers 2012). Just a month later, a flying female was encountered in Constance, in the very South of Germany (Heckmann 2012). Four years later, the species was considered established in the surroundings of Lake Constance after repeated findings (Heckmann 2016). Haye and Zimmermann (2017) reported several records from the vicinity of Basel, Freiburg, and Constance, as well as single specimens found in Stuttgart and Berlin. All findings by Haye and Zimmermann (2017) were made in 2015–2016 by the authors or reported in the same years by citizen scientists at the online portal www.halyomorphahalys.com. Morkel and Dorow (2017) documented the northwards spread of *H. halys* in Germany by reporting two specimens collected by the second author in Frankfurt on Main 2015 and 2016. They concluded that the species must already have been established in the region by that time. Hanselmann (2016) found a couple of dozen *H. halys* in Mainz, on and around the building of the local Natural History museum. Morkel and Renker (2019) presented a digest of the observations by citizen scientists from Frankfurt, its surroundings, and from Wiesbaden and Kassel (the voucher photo for Kassel that they cited was not available on the platform as of 24.08.2021), made mostly in the year 2018. The findings concentrated in and around the city of Frankfurt, with only one record from a protected area in Flörsheim (Main), Weilbacher Kiesgruben. Kott (2019a) evaluated more northern citizen science records from Northern Rhine-Westphalia (NRW), where the species was recorded in Krefeld, Bochum, Duisburg, Essen, and Cologne in 2018, and in Oberhausen and Cologne in 2019 (see also Schäfer 2019 for a summary for NRW). Finally, Hoffmann (2021) summarized new records from citizen science pages and cited 18 locations from Bavaria and three from Saxony, where *H. halys* was found in the meantime, as well as single findings for Lower Saxony (Braunschweig), Saxony-Anhalt (Halle) and Bremen. He also added several more records from NRW; some other records that he cites are without voucher photo and cannot be evaluated. Thus, as of now, *H. halys*

is recorded in the literature for almost all German states except for Saarland, Thuringia, Mecklenburg-Vorpommern, Hamburg and Schleswig-Holstein.

Here, we report the first documented findings of *H. halys* from Hamburg, corroborated by photos and with voucher specimens deposited in the collection of the Zoological Museum in Hamburg (ZMH). Several specimens from Hamburg were also studied using DNA-barcoding. In addition, records from several other locations in Northern Germany, made by citizen scientists on online platforms or by staff of natural history museums, are presented. Possible economic consequences of the northward spread of *H. halys* are discussed.

Materials and methods

In addition to our own collections, records for *H. halys* on the citizen science platforms iNaturalist.org, naturgucker.de, and neobiota-hamburg.de were evaluated. Colleagues from natural history institutions in Northern Germany were requested to report occurrences of the species. For online platforms, only those records with a voucher photo were considered and only the finds from Northern Germany were included in the present study. We define Northern Germany as the area of Germany north of the 52. parallel (roughly corresponding to the line between the cities of Münster and Magdeburg), which constitutes most of the North German Plain geographical region. Only the records present on the platforms as of 06.11.2021 were considered in the present study. Berlin was excluded from the survey, since *H. halys* has been known from the city for a longer time already (Haye and Zimmermann 2017) and plenty of records exist on the online platforms. All certain records are listed in Suppl. material 1: Table S1. A distribution map was created with QGis 3.16.10 and enhanced with GIMP 2.10.24.

For DNA barcoding sensu Hebert and co-authors (2004), six specimens from two locations in Hamburg-Hamm (53°33'25.2"N, 10°03'09.1"E; 53°33'25.5"N, 10°03'13.5"E) were analyzed. Specimens are deposited in the Zoological Museum of Hamburg (ZMH). DNA was extracted from one leg of each specimen using a Chelex protocol (Walsh et al. 1991) and the DNA barcoding fragment of the partial cytochrome *c* oxidase subunit I (COI) sequence was amplified with the primers HCO / LCO (Folmer et al. 1994) using a standard PCR protocol. Sequencing was performed by Macrogen, Inc. (Amsterdam, NL). Furthermore, 42 sequences including most known locations in Europe were downloaded from BOLD and NCBI (Suppl. material 2: Table S2.) for comparison. One sequence of *Raphidogaster nebulosa* (EBUG1254-12) served as outgroup for phylogenetic analysis. All sequences were aligned using MUSCLE (Edgar 2004) as implemented in Geneious v. 6.1.8. (Kearse et al. 2012). The alignment was trimmed to 615 bp. For the haplotype network analysis, the outgroup sequence was removed ($n = 47$ sequences remained).



Figure 1. **A.** Habitat in Hamburg-Hamm; **B.** *Halyomorpha halys* nymph in situ on a *Rubus fruticosus* leaf; **C.** An older nymphal instar photographed in the lab.

A TCS network was constructed using PopArt (Leigh and Bryant 2015) with the default parameters and different color coding for each country.

Results

M. Heller reported three juvenile specimens (ZMH844214–ZMH844216) from a Nasturtium plant on his balcony in Hamburg-Hamm ($53^{\circ}33'25.2''N$, $10^{\circ}03'09.1''E$) on the 07.07.2021 at the online portal www.neobiota-hamburg.de. Three additional specimens were collected by the authors on 23.07.2021 (ZMH844217–ZMH844219) and further specimens were recorded on the 25.08.2021 and 13.09.2021 close to the original location ($53^{\circ}33'25.5''N$, $10^{\circ}03'13.5''E$) on *Rubus fruticosus*. Morphological identification was unequivocal, as *H. halys* is the only pentatomoid species in Germany bearing large spines on the pronotum as nymphs (Fig. 1). On 27.08.2021, several additional nymphs were obtained from Hamburg-Wandsbek, where they were found on mint ($53^{\circ}34'39.27''N$, $10^{\circ}5'13.9776''E$). Finally, a photo of an adult specimen that was made three years ago on 30.10.2018 in Hamburg's inner city ($53^{\circ}32'44.624605''N$, $9^{\circ}59'34.884664''E$) was submitted to www.neobiota-hamburg.de in November 2021.

The species identification was further confirmed by DNA barcoding. Five specimens were successfully sequenced. All sequences represented a single haplotype. The sequence was deposited in NCBI Genbank under accession MZ828400. It represents the haplotype H3 from Yan et al. (2021) and Gariepy et al. (2021) and matched other sequences of *H. halys* in BOLD and GenBank with 100%; several sequences (specimens from Serbia, Hungary, China, Austria and Italy) clustered with it (Fig. 2).

In addition, the online citizen science platforms iNaturalist.org and naturgucker.de delivered records of *H. halys* of which the IDs could be verified by photos. Two reports from Hamburg (one from Schnelsen in Eimsbüttel and another without precise coordinates) were uploaded on iNaturalist in October 2021. There was also a single adult specimen from Bremen (campus of Bremen University, Horn-Lehe) and a single adult from Braunschweig (carpark of Johann Heinrich von Thünen Institute) collected by museum staff. iNaturalist.org and naturgucker.de delivered additional records for other cities in Northern Germany: Osnabrück (1), Hameln (1), Magdeburg (1), Müritz National Park (1), Kaltenweide in the region of Hannover (1), Braunschweig (2) and Hannover (4). All collection information is summarized in Suppl. material 1: Table S1. The findings from citizen science platforms and by colleagues from natural history institutions are presented along with our own records in Fig. 3.

Several records from citizen science platforms were not considered valid due to poor quality photos or depicting first nymphal instars that are not easy to distinguish from other species of Pentatomidae): Bremen (<https://www.inaturalist.org/observations/63811907>), Rehhorst (<https://naturgucker.de/?bild=1147003753>), Lüneburg (<https://naturgucker.de/?bild=231118762>), Hannover (<https://naturgucker.de/?bild=170137063>). Also, there is a record from Estedt (Saxony-Anhalt) made on 31.03.2019 (naturgucker.de), a record from the vicinity of Wennigsen (Lower Saxony) made on 07.06.2020 and a record from Strausberg (Brandenburg) made on 11.08.2021 (naturgucker.de) that cannot be verified due to the lack of a photo.

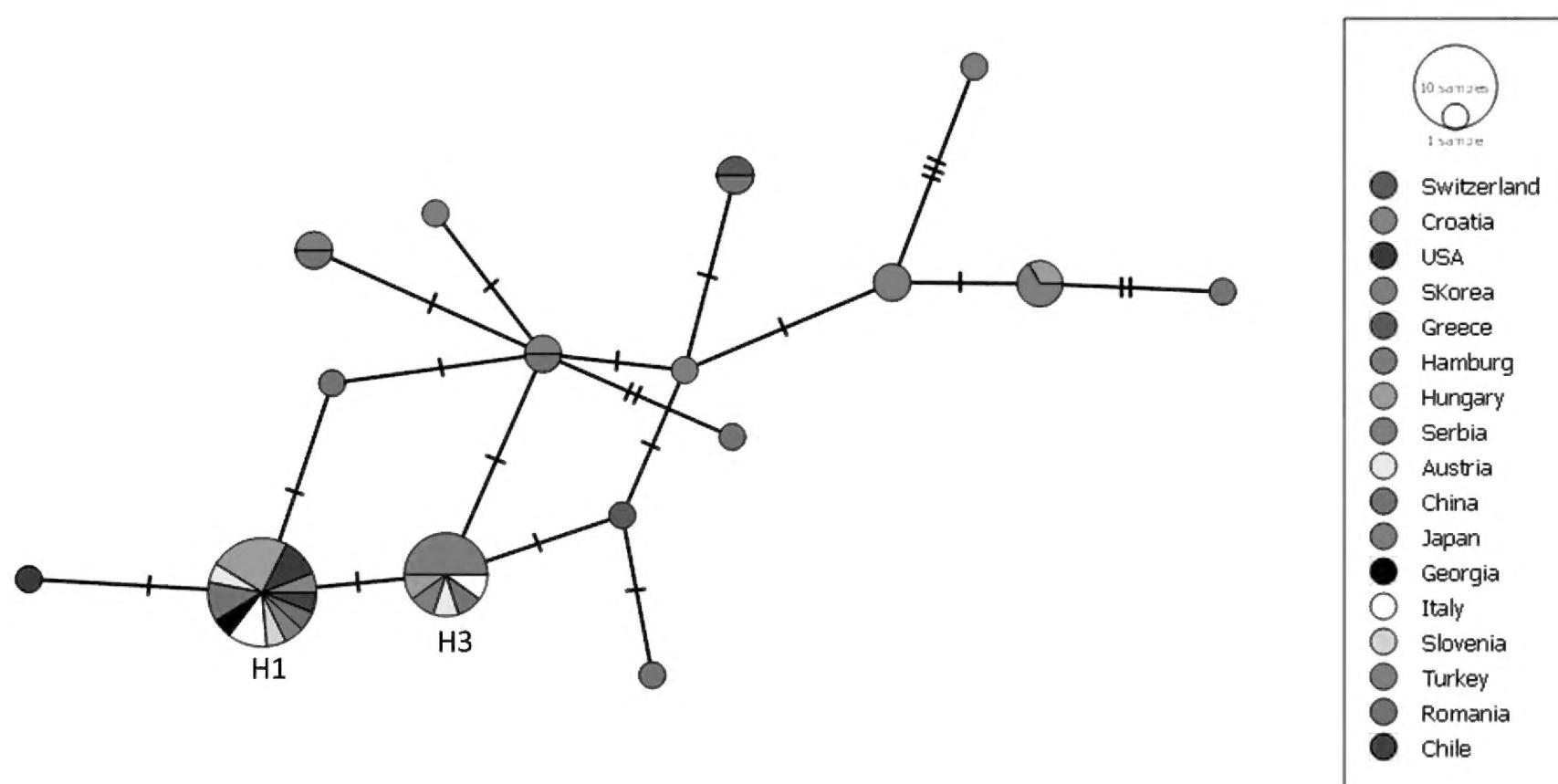


Figure 2. TCS haplotype network generated for COI-sequences of *Halyomorpha halys* specimens from Hamburg and those available via NCBI and BOLD. Each line represents a single mutational change whereas small black lines indicate missing haplotypes. The diameter of the circles is proportional to the number of haplotypes sampled (see given open circles with numbers). The most common haplotypes H1 and H3 are marked.

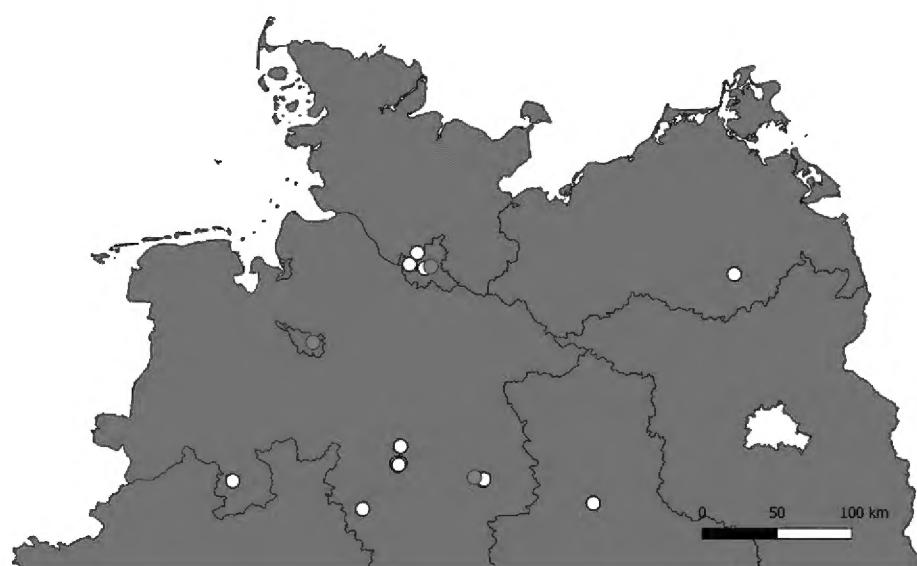


Figure 3. *Halyomorpha halys* distribution in Northern Germany, own records (dark red) and records from citizen science platforms (white). Berlin is coloured all white due to numerous records that are not shown here in detail. Made with QGis 3.16.10.

Discussion

Distribution in Germany

The specimens collected or documented in Hamburg provide the first record of the invasive *H. halys* for this German state. Together with first occurrences in Bremen and Mecklenburg-Western Pomerania (Suppl. material 1: Table S1.) and previous records for Lower Saxony and Saxony-Anhalt (Hoffmann 2021; Suppl. material 1: Table S1), as well as reliable records of the species from Thuringia and Saarland on iNaturalist.org, the species is now known from every German state except Schleswig-Holstein (SH). Due to the fact that Hamburg has a direct border to SH and as *H. halys* steadily spreads northwards since it was detected in the very south of Germany (Heckmann 2012), an occurrence in SH is probably only a matter of time.

However, it is interesting to note that predictions of possible geographical occurrence based on ecological niche modelling did not anticipate the arrival of *H. halys* in Northern Germany in all models. The model applied by Kriticos et al. (2017) rendered this region as unsuitable for the species. Yet, in the study of Zhu et al. (2012), a MaxEnt model yielded large parts of northern Europe, including the whole of Germany, as the potential distribution area, whereas a GARP model applied in the same study did not.

Patterns of expansion

The distribution patterns of *H. halys* and factors determining its distribution have been subject of many studies (summarized in e.g. Lesley and Nielsen 2018). In general, *H. halys* tends to occur in cities, probably profiting from the “heat islands effect”; findings from rural areas in Europe are scarce, with the exception of Italy (Haye and Zimmermann 2017). This preference for cities is well documented: Veteck et al. (2018) detected most specimens in the residential areas of Hungarian cities. Kotts (2019b) found the species more commonly in the inner city of Cologne and less often in the outskirts. Here, *H. halys* preferred *Catalpa bignonioides* and *Paulownia tomentosa* – widespread ornamental trees of East Asian origin – as host plants (Kotts 2019b). Zimmermann et al. (2018) also suggested that *H. halys* first established on urban ornamental woody plants and later started spreading in gardens and orchards.

Based on the number and age of the detected specimens in the invasive area and the circumstances of their detection, four relative stages of their range expansion,

colonization, and invasion spread can be described. These stages probably do not reflect any biological characters of *H. halys*, but help to characterize the probable current condition of a local population (Fig. 4). The first stage, where only few colonizing adults are found that might not have established a local population yet, is likely the condition observed in Great Britain at the moment (Powell et al. 2021). For German states, it was documented by Heckmann 2012 (Baden-Württemberg) and Morkel and Dorow 2017 (Hesse). At the second stage, a population is established and both adults and nymphs of the species are detected (Heckmann 2016, Haye and Zimmermann 2017, for Baden-Württemberg and Morkel and Renker 2019 for Hesse). This is the stage currently observed in Hamburg; several findings have been made in different parts of the city, the nymphs being quite young in July and reaching the 5th instar by August. The Hamburg population seems to be univoltine, since only nymphs were encountered during summer and such a slow development pace would not allow more than one generation per year. The population sizes are still small, as only a few individuals were detected at every occurrence. Nevertheless, it is reasonable to assume that *H. halys* successfully reproduces in Hamburg. The third descriptive stage of the spread is reached when the species becomes so numerous that specimens are frequently detected by local residents when the true bugs enter homes in autumn to overwinter there and are reported as a nuisance. This stage has probably not yet been reached in Hamburg, since there were only two reports of the species from the city on citizen science platforms this autumn (as of 06.11.2021). In contrast, there are hundreds of records on citizen science platforms from the southern German states, e.g. Hesse and Baden-Württemberg. Finally, at the fourth stage, the species reaches mass occurrences; this is probably also the stage when *H. halys* populations start expanding their range

to the countryside (all previous stages normally take place largely within cities). Mass occurrences have been documented for Baden-Württemberg (e.g. Höhl 2018), but not yet for Hesse, where the bugs already occur in the countryside there, albeit in small numbers (VH, personal observations from Campo Pond protected area, Southern Hesse). The stage of mass occurrence is a prerequisite for the species to become a pest and a threat to local economy.

Potential economic impact

The question of the possible economic impact of *H. halys* in Hamburg and neighboring areas is a complicated one. On the one hand, since the species is known to damage fruit (Leskey and Nielsen 2018), Hamburg and its surroundings are an area of concern. In the southwest, the city borders the “Altes Land” region, the largest coherent fruit production area in Northern Europe. Altes Land is responsible for ca. 30% of German apple production, numbering around 300.000 tons per year (Görgens 2013). The total amount of fruit production in the region is worth about 180 million € (Verein für die Anerkennung des Altes Landes zum Welterbe der UNESCO e.V. 2021). If *H. halys* becomes established in the region and reaches high population numbers, it may cause significant economic damage.

On the other hand, not every region where this invasive species was established is doomed to suffer serious economic damage. Examples from the USA (Leskey and Nielsen 2018), Italy (Bariselli et al. 2016) or Switzerland (National Centre for Climates Services 2021), where the species causes massive problems in agriculture, are dramatic, but they all concern warmer regions. It seems that *H. halys* needs longer to reach the high numbers necessary to cause economic damage the further to the North it spreads. In Italy, it only took 2–3 years from

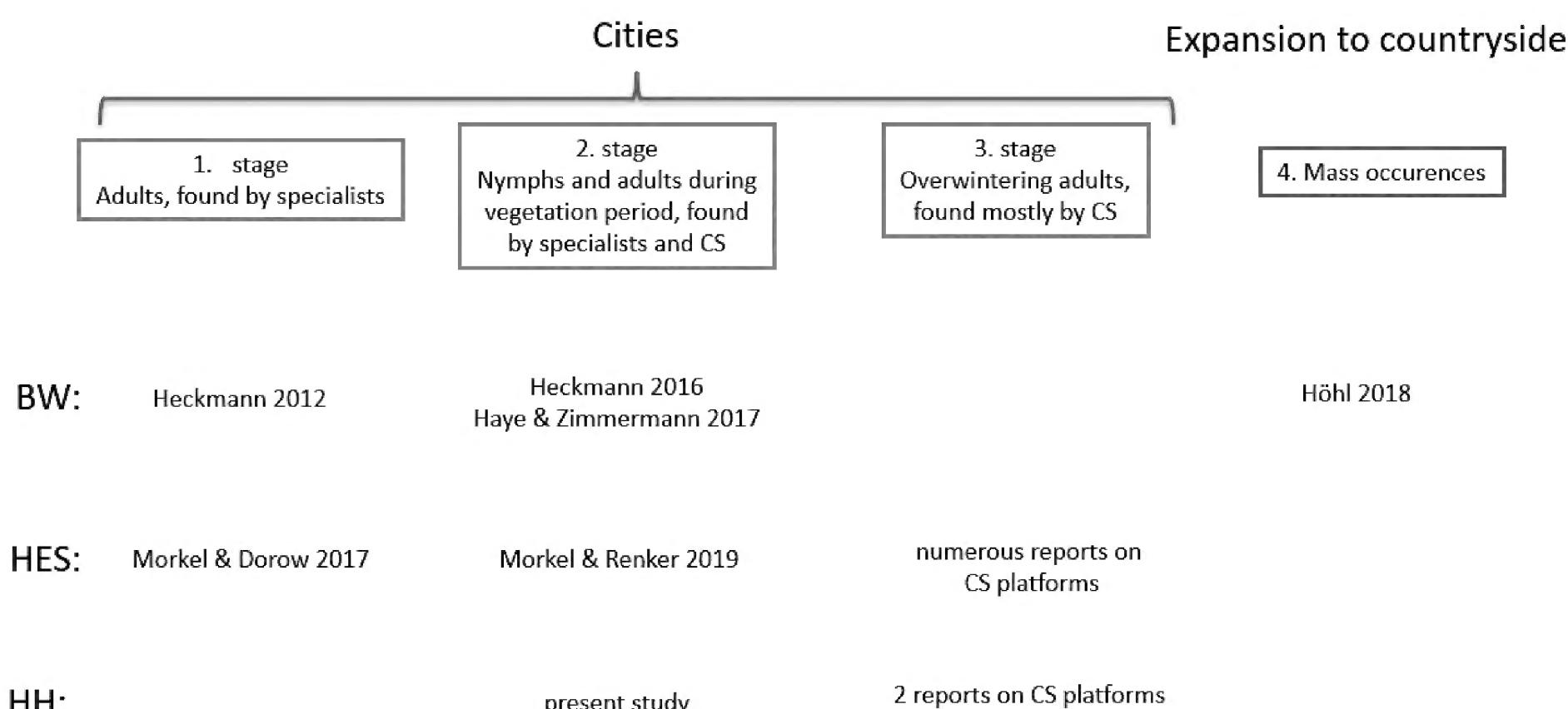


Figure 4. A model of expansion for *H. halys*, with publications documenting its stages in German states. Mass occurrences have already been documented in BW, but not in HES or HH. BW = Baden-Württemberg, HES = Hesse, HH = Hamburg; CS = Citizen Scientists.

the first documented record of the species in 2012 and first reports of economic damage (Maistrello et al. 2014, Bariselli et al. 2016), although the species might have been present in the country earlier. In Switzerland, 11 years passed between the first records in 2004 (Wermelinger et al. 2008) and the first severe damage reported in 2015 (National Centre for Climate Services 2021). The first record in Germany lies nine years back (Heckman 2012) and the species has regularly been cited as an organism of a special concern (Höhl 2018, Pflanzenschutzamt Berlin 2020). However, no reports of significant economic damage have been published for Germany yet, even for its southern states. A specialist from a gardening consulting company in Heilbronn, Baden-Württemberg, reported that the species is well-known in the region and monitored with concern, but the patterns of economic impact are not unequivocal: some of the businesses supervised by the company report almost no economic damage, whereas some others do report significant crop loss (Steinle, pers. comm.). In Hungary, economic damage was reported only in one case of 138 studied occurrences (Vetek et al. 2018).

The ecological niche model studies cited above (Zhu et al. 2012, Kriticos et al. 2017) were ambiguous concerning the suitability of the Northern Germany as a habitat for the species, indicating that the area might not be optimal (yet). Finally, Leskey and Nielsen (2018) make an – admittedly quite speculative – suggestion that the haplotype H1 is responsible for the most damage to agriculture in Italy and USA, and the haplotype H3 registered now in Hamburg may be of less concern.

All this is of course not a good reason to give up caution, even for Hamburg, since climate change may alter the situation and make the region more suitable for *H. halys* in the future. Still, the circumstances described above may provide some time to establish a monitoring scheme in the region (probably involving citizen scientists, since such an approach proved to be a valuable tool in the study of the species as e.g. Vetek et al. 2018 or Maistrello et al. 2016 demonstrated) and devise a strategy to keep the invasive species at bay.

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Supplementary material 1

Table S1

Authors: Viktor Hartung, Martin Heller, Martin Husemann
 Data type: excel file
 Explanation note: Records of *Halyomorpha halys* in Northern Germany
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Supplementary material 2

Table S2

Authors: Viktor Hartung, Martin Heller, Martin Husemann
 Data type: docx file
 Explanation note: Sequences used for COI network analysis
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